FOUR WATERFLOODING PROJECTS IN COWLEY COUNTY, KANS., 1958

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by

J. P. Powell,[2] J. E. Eakin,[2] K. H. Johnston,[2] and C. H. Riggs[2]

SUMMARY AND INTRODUCTION

This report provides information on the techniques and results obtained on representative waterflooding projects in Cowley County, Kans. Records show that waterflooding was begun as early as 1935, but not until 1948 was the method expanded. The greater depths to the oil-producing formations in this area compared to those in eastern Kansas undoubtedly delayed the widespread use of secondary-recovery methods. This report presents a discussion of four waterflooding projects in Cowley County, Kans. The locations of these projects are shown in figure 1. The projects have been in operation from 1 to 7 years and have produced more than 1 million barrels of additional oil by injecting 11.5 million barrels of water.

The projects are designed to take advantage of elevation and height of the separator tank to collect by gravity flow the produced brine at the respective treating or storage tanks. The closed-type water system is used on three of the projects and an open-type water conditioning system on the fourth. On one of the projects, which was drilled along a narrow shoestring formation, alternate wells were converted to input wells. However, most of the input wells for flooding were converted producing wells.

Discussion of the individual projects includes information on the early history, the source and treatment of water used for flooding, production-decline curves, typical core analyses and electric logs, water analyses, and results of waterflooding.

ACKNOWLEDGMENTS

This report on waterflooding in Cowley County, Kans., was prepared by the Bureau of Mines under a cooperative agreement with the Kansas State Board of Health.

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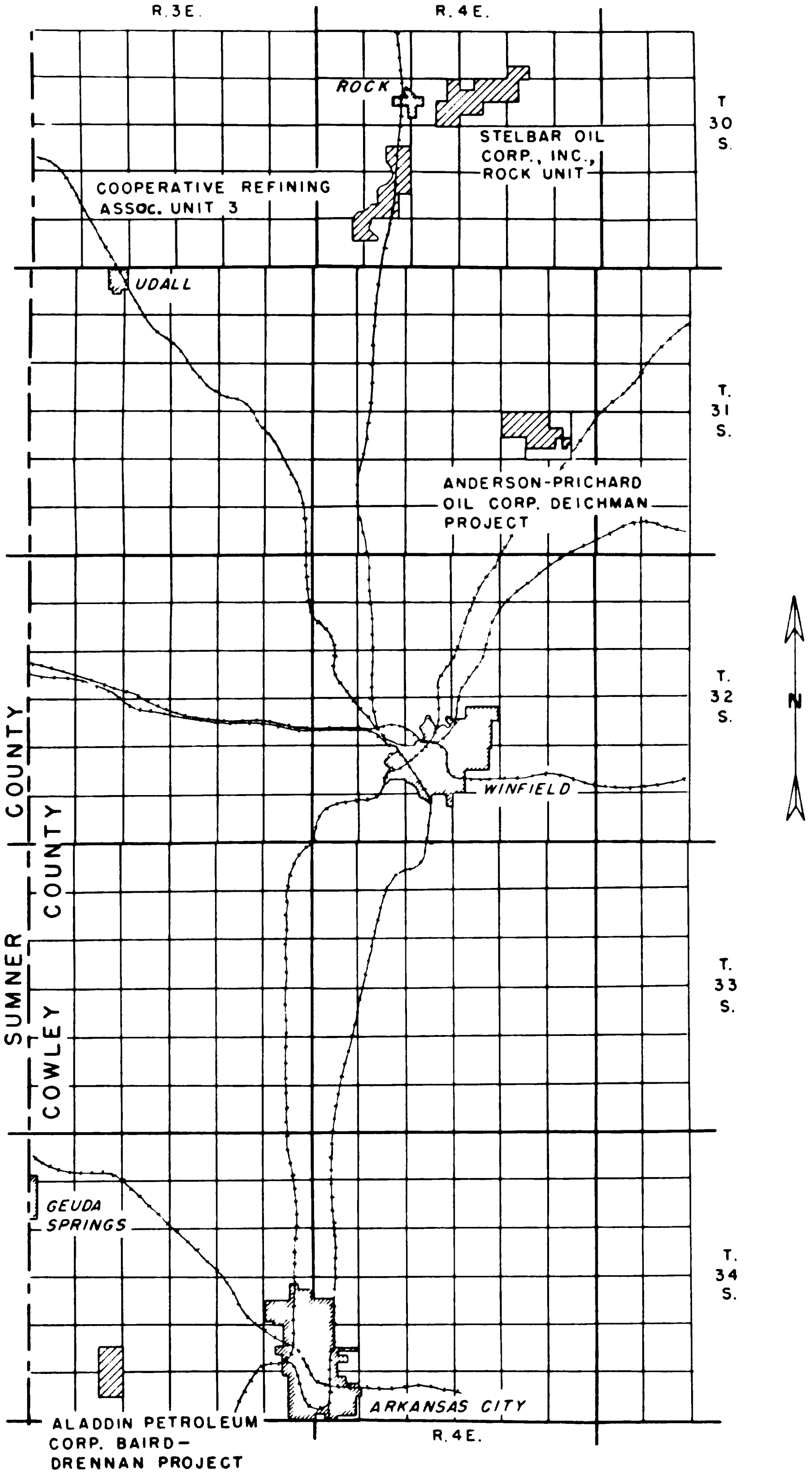
R.3E.
R.4E.
ROCK
STELBAR OIL CORP., INC., ROCK UNIT
COOPERATIVE REFINING ASSOC. UNIT 3
T 30 S.
UDALL
T. 31 S.
ANDERSON-PRICHARD OIL CORP. DEICHMAN PROJECT
N
T. 32 S.
WINFIELD
SUMNER COUNTY
COWLEY COUNTY
T. 33 S.
GEUDA SPRINGS
T. 34 S.
ARKANSAS CITY
ALADDIN PETROLEUM CORP. BAIRD-DRENNAN PROJECT
R.4E.

Figure 1. - Map showing location of four waterflooding projects in Cowley County, Kans., March 1, 1958.

DISCUSSION OF INDIVIDUAL PROJECTS

Stelbar Oil Corp., Inc. Rock Pool Unit

In June 1949 several operating companies unitized leases in secs. 11, 14, 15, and 16, T. 30 S., R. 4 E., Rock field, Cowley County, Kans., for waterflooding. The Stelbar Oil Corp., Inc., operator of the Rock Pool unit, began to inject water into converted oil wells on the property in January 1951. Individual wells operated by Stelbar on four leases outside the unit were drilled to take advantage of the flood and are included in the project. Figure 2 is a map showing the production history of the project. A total of 460 acres was affected by the flood to March 1, 1958. Probably the most outstanding features of this flood are its simplicity and profitable results.

The producing formation is known locally as the Bartlesville sand. In this particular area the sand averages 20 feet in thickness and 2,765 feet in depth. Analysis of a representative core is shown in figure 3. Average porosity was 18.2 percent and the permeability, 15 millidarcys. The average oil saturation of the core was 32 percent and water saturation, 45 percent, although the core may have been partly flushed in coring.

Analysis of a sample of oil produced from a representative well on the unit property showed that the gravity of the oil was 38.4° API. Viscosity measurements of 3.9 centipoises at 77° F. and 3.2 centipoises at 100° F. indicated that the oil should have a favorable oil-water mobility ratio.

History Before Flooding

The discovery well in Rock field in the northeast corner of sec. 15 was completed on January 19, 1923, by Smith and Ash, with a production rate of 125 barrels of oil per day. Among the other early developers of the new pool were Shawver & Sutter, Prairie Oil & Gas Co., and Gypsy Oil Co. Although the greatest natural production for a well completed during original development was 150 barrels of oil a day, some wells produced as much as 275 barrels of oil after shooting. Average initial oil production was 115 barrels a day.

By October 1923 the field's daily rate of oil production was 763 barrels. A peak annual rate of 226,000 barrels of oil was reached in 1924. By 1927 the annual rate of oil production from 19 wells had declined to about 98,000 barrels. Very small volumes of gas were produced with the oil, and formation water was reported in only a few dry holes. Additional wells were drilled in the pool during the 1935-39 period.

Available records of oil produced from the various leases by primary methods show that an accumulated 1,972,873 barrels of oil was recovered by June 1, 1949. Approximately 45,000 barrels of additional oil had been produced from the unit to January 1952, when the first increase in oil production came from water injection. In lieu of complete records a monthly record of oil produced during 1951 was included in figure 2 and table 2 to show the results of the injection of water.

Method of Completing and Operating Wells

The original wells and those drilled during the 1935-39 period were completed with 40 to 100 feet of either 8 5/8- or 10 3/4-inch surface casing cemented in place and a production string of either 5 3/16- or 5 1/2-inch casing set and cemented at

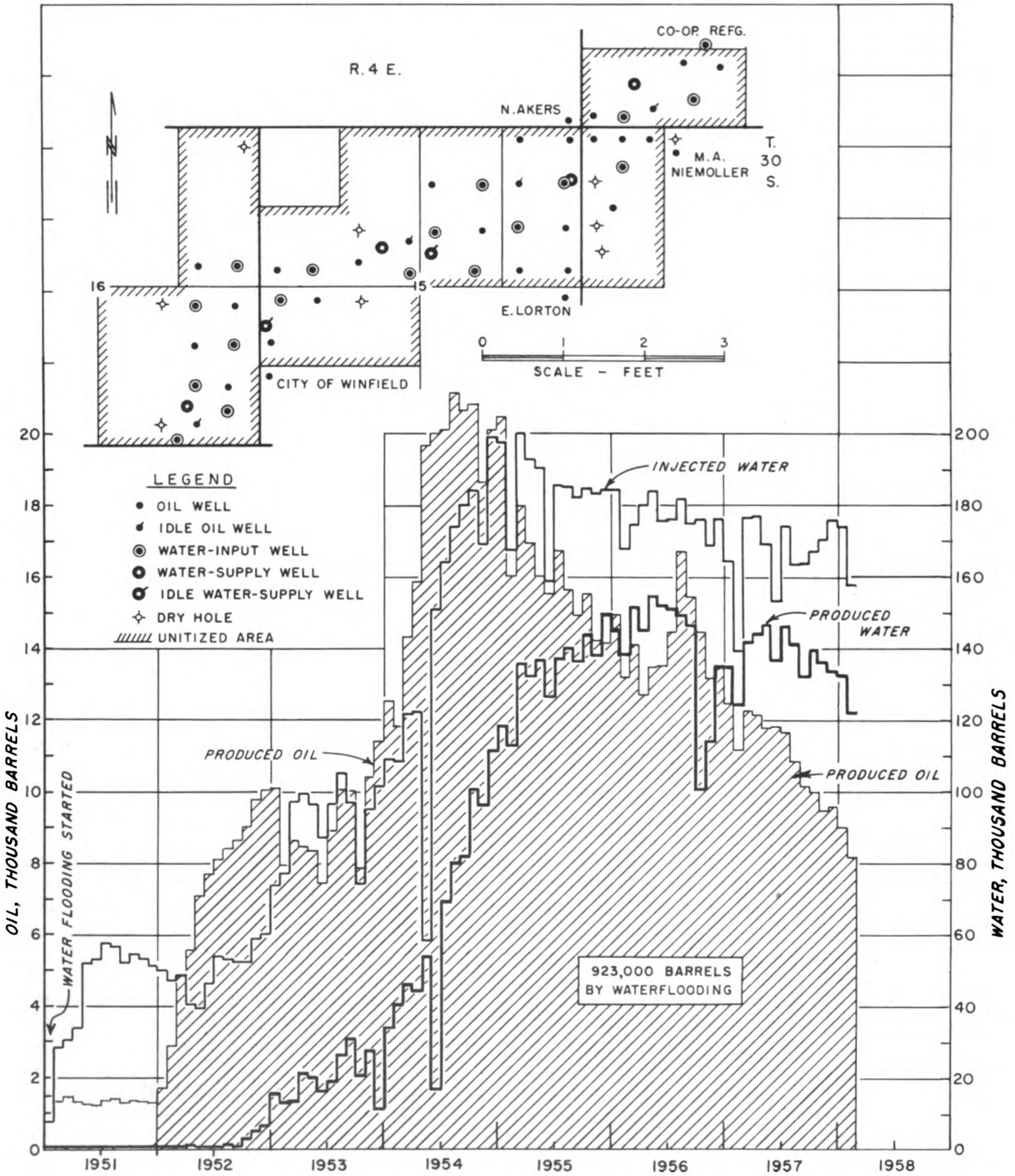

Figure 2. - Map and production history of Stelbar Oil Corp. Rock Pool unit, Rock field, Cowley County, Kans., March 1, 1958.

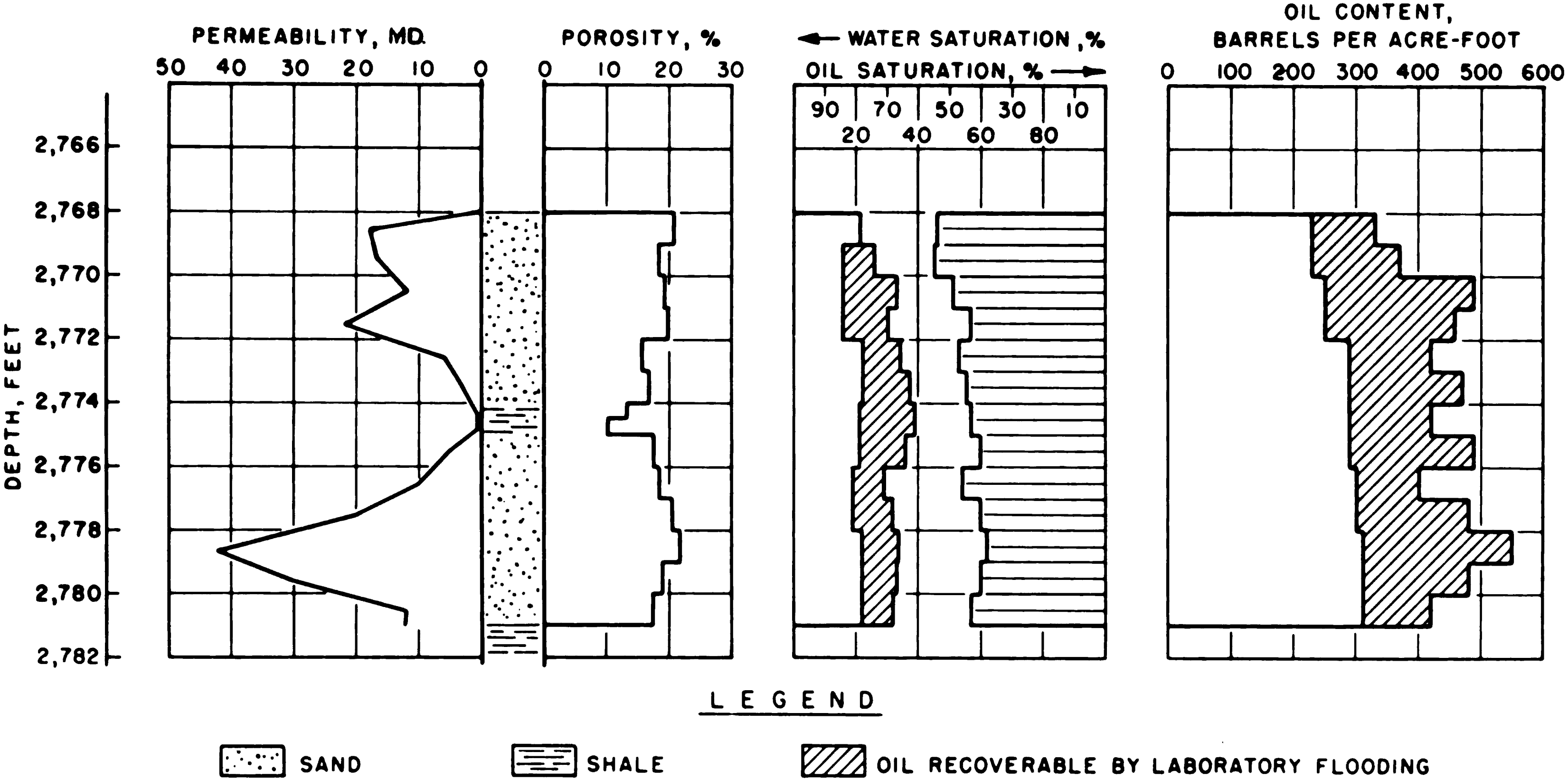

Figure 3. - Representative core analysis of Bartlesville sand, Stelbar Oil Corp. Rock Pool unit, Rock field.

the top of the Bartlesville sand. During the drilling several intermediate casing strings were required to exclude water. All wells were shot with 2 to 4 quarts of nitroglycerin per foot of sand or an average shot of 36 quarts per well. Conventional pumping equipment, including 2-inch tubing, was used, and wells were pumped by the beam and back-crank method. In March 1958 the original pumping equipment had been replaced with heavy-duty pumping units powered by electric motors.

Thirteen former oil wells on the unit were converted to water injection by pulling rods and tubing and cleaning the wells to bottom; usually 1 or 2 days' rig time was required. Four new input wells were drilled during the development of the flood. Water is injected directly through the casing in most input wells, but tubing and packers were required in a few wells after tests showed casing leaks.

Source and Treatment of Water

Water from a supply well completed in the Douglas sand at a total depth of 810 feet was the original source of water for injection. The well was cased with 36 feet of 15 1/2-inch surface pipe and 8 5/8-inch casing set at the top of the Douglas sand at 759 feet and cemented with 35 sacks of cement. Swabbing tests recovered 80 barrels of water during the first hour and an average of 55 barrels of water per hour over a 4-hour period. Installation of a pumping unit on the original supply well resulted in the injection of 400 and 550 barrels of water a day directly into 2 input wells. Later, another Douglas water-supply well was completed, and an injection plant was constructed. Three water-supply wells also were completed in the Stalnaker sand at about 1,850 feet with 7-inch casing landed through the sand, cemented, and then perforated. The wells were tubed with 4-inch tubing and equipped with 3 3/4-inch insert pumps operated by individual surface units.

Because of the corrosive quality of the shallower Douglas water, that source was discontinued in favor of water from the Stalnaker sand. In November 1953 the operator began to dispose of the corrosive produced water into one of the former Douglas supply wells. This operation was continued until most of the Douglas water had been eliminated from the system.

Two separate plants serve the unit because the oil-productive limits of the leases are confined to a narrow belt 2 miles long, which ranges in width from one location to about 1/2 mile. Water for injection through the west plant, on the city of Winfield lease, is supplied by 1 Stalnaker well and by brine produced from 9 active oil wells and is distributed to 8 input wells.

The tank battery which is adjacent to the water-injection plant, and produced brine from the gunbarrels flow into a 250-barrel, 10- by 15-foot settling tank. The movement of a float in this tank aids the plant man in regulating the operating time of the supply well. Produced brine from the settling tank flows into a 200-barrel oil-sealed mixing tank along with water from the supply well. A 6- by 5-foot pressure filter, used in the original operation, was bypassed when injection rates exceeded the capacity of the filter. The mixing tank contains an electrode-type safety switch to shut off the high-pressure injection pump when the water level is too low. Mixed water is drawn from the 200-barrel tank by a 4 1/2- by 2-inch horizontal triplex pump powered by a 75-hp. electric motor. The pump has a high-pressure head and 3-inch ceramic plungers. A safety valve on the discharge line is set to bypass water to the suction line at 1,200 p.s.i. Injection water, at about 1,200 p.s.i., is forced through a manifold from which 2- and 3-inch distribution lines serve the input wells.

Although the water is neither chemically treated nor filtered, injection trouble has been negligible. In the past some water-input wells have been treated with acid. During the past 2 years it has not been necessary to treat the wells to maintain their injection characteristics, although some of the water-input wells on the west side of the unit have shown indications of plugging. In 1955 injection rates began to decrease, while injection pressures gradually increased, probably because of the deposition of barium salts.

Two edge producing wells on the west end of the unit are treated through the casing with 1 quart of chemical per day to stop the formation of gyp. Some producing wells in the east end of the unit have received similar treatment.

Samples of the Stalnaker supply water and the produced brines were analyzed for mineral content. Results of these analyses are included in table 1. These analyses show the potential plugging agent barium in each sample.

The east plant, using water from 2 Stalnaker wells and 13 oil-producing wells, is operated similarly to the west plant; it serves 9 input wells.

TABLE 1. - Mineral analyses of injection waters, Stelbar Oil Corp., Inc., Rock Pool unit

Ions or radical	Supply-well water		Produced brine	
	P.p.m.	Reacting values, percent (Palmer)	P.p.m.	Reacting values, percent (Palmer)
Calcium (Ca)	7,600	6.66	7,600	6.78
Magnesium (Mg)	2,640	3.81	2,630	3.86
Sodium (Na)	51,800	39.53	50,700	39.36
Carbonate (CO_3)	0	0	0	0
Bicarbonate (HCO_3)	88	.03	104	.03
Sulfate (SO_4)	trace	0	137	.05
Chlorides (Cl)	100,900	49.97	99,100	49.92
Total solids	163,028	100.00	160,271	100.00
Hydrogen sulfide (H_2S)	None		None	
Barium (Ba)	53 p.p.m.		20 p.p.m.	
Specific gravity	1.112		1.112	

Results of Flooding

Waterflooding was begun on the Rock Pool unit in January 1951, and the first increase in the rate of oil production was noted in January 1952. Table 2, a summary of operations, includes data relating to the flood. Figure 2 shows that a maximum producing rate of over 21,000 barrels of oil per month was reached in August 1954. To March 1, 1958, about 10,626,000 barrels of water had been injected, and approximately 923,000 barrels of waterflood oil was recovered from the 460 acres flooded. By that time the cumulative water-injected to oil-produced ratio was 12 to 1.

TABLE 2. - Summary of operations, Stelbar Oil Corp., Inc., Rock Pool Unit, Rock field, Cowley County, Kans.

Location - secs. 11, 14, 15, and 16,
T. 30 S., R. 4 E.
Sand flooded - Bartlesville
Depth to top of sand - 2,765 feet
Average sand thickness - 20 feet
Area flooded - 460 acres
Well pattern - irregular

Type of water - brine
Type of system - closed
First water injection - January 1951
First oil increase - January 1952
Status - active
Gravity of oil - 38.4° API
Viscosity of oil - 3.9 cp. at 77° F.
3.2 cp. at 100° F.

Data to March 1, 1958

	Barrels
Primary oil recovered, estimated (330 acres)	2,019,000
Primary oil recovered per acre, estimated (330 acres)	6,118
Oil recovered by waterflooding (460 acres)	923,000
Oil recovered per acre by waterflooding (460 acres)	2,007
Water injected	10,626,043
Water injected per acre	22,380
Water produced beginning January 1951	6,237,365

Summary of waterflood performance

Date	Acres flooded	Active input wells	Average wellhead pressure, p.s.i.	Active oil wells	Oil recovery, bbl. per acre	Cumulative water-injected to oil-produced ratio
Dec. 31, 1951	180	8	Vac.	21	-	-
Dec. 31, 1952	210	10	(1/)	24	400	14
Dec. 31, 1953	420	14	409	22	462	12
Dec. 31, 1954	430	15	615	24	953	10
Dec. 31, 1955	430	15	934	24	1,403	10
Dec. 31, 1956	450	16	986	22	1,718	11
Dec. 31, 1957	460	17	888	21	1,969	11
Feb. 28, 1958	460	17	881	22	2,007	12

1/ No record.

Monthly record of water injected and oil and water produced, barrels

	1951			1952		
	Water injected	Oil produced	Water produced	Water injected	Oil produced	Water produced
January	7,887	2/ 1,487	388	50,024	3/ 1,718	434
February	28,474	1,316	364	47,203	2,882	435
March	30,625	1,440	527	48,284	4,840	527
April	33,769	1,317	489	40,614	5,573	840
May	51,574	1,274	341	39,485	7,093	496
June	52,972	1,222	330	46,490	7,702	540
July	57,777	1,348	341	54,113	8,102	589
August	56,681	1,399	217	52,902	8,400	899
September	52,141	1,302	270	52,380	8,639	600
October	54,686	1,349	124	52,522	9,009	3,317
November	53,390	1,341	300	59,015	9,781	5,610
December	51,158	1,309	341	60,288	10,310	6,603
Total	531,134	2/16,104	4,032	603,320	84,049	20,890

2/ Included as primary oil production. 3/ Included as waterflood oil production.

TABLE 2. - Summary of operations, Stelbar Oil Corp., Inc., Rock Pool Unit, Rock field, Cowley County, Kans. (Con.)

Monthly record of water injected and oil and water produced, barrels (Con.)

	1953			1954		
	Water injected	Oil produced	Water produced	Water injected	Oil produced	Water produced
January	73,966	10,633	15,779	108,684	12,480	34,000
February	77,234	7,952	13,272	108,534	11,830	40,516
March	97,236	8,626	13,392	121,510	14,342	46,531
April	99,391	8,461	21,240	122,306	15,851	44,280
May	96,601	8,349	20,150	58,629	19,661	54,157
June	87,015	7,439	16,500	150,672	19,954	16,950
July	96,441	8,885	19,087	163,992	20,066	69,315
August	105,069	10,076	26,604	173,803	21,085	80,104
September	96,970	10,047	30,860	180,073	20,655	82,027
October	73,982	7,861	20,695	184,127	20,882	100,603
November	95,057	10,413	27,493	169,151	18,630	96,337
December	101,421	11,402	11,370	199,289	20,174	111,298
Total	1,100,383	110,144	236,442	1,740,770	215,610	776,118
	1955			1956		
January	197,758	20,417	118,575	184,100	14,920	144,941
February	167,813	16,000	112,840	167,619	13,167	138,549
March	200,232	17,939	135,563	174,451	14,076	151,411
April	192,540	16,906	132,300	179,546	12,659	144,870
May	190,511	15,987	136,772	183,492	13,526	154,256
June	158,705	15,485	126,456	175,359	13,672	151,920
July	185,529	16,714	137,129	175,709	14,493	151,063
August	184,974	15,599	140,182	181,675	16,673	149,203
September	182,119	14,899	136,500	174,520	15,416	146,228
October	184,612	15,530	143,701	175,513	14,421	100,595
November	182,910	14,182	138,045	168,593	13,131	114,050
December	184,107	14,092	149,560	175,681	13,473	135,532
Total	2,211,810	193,750	1,607,623	2,116,258	169,627	1,682,618
	1957			1958		
January	164,282	12,433	135,125	173,533	8,957	132,548
February	138,919	11,156	124,010	157,597	8,098	121,660
March	176,378	12,228	141,608			
April	176,498	12,075	144,030			
May	168,743	11,744	146,568			
June	153,142	11,750	136,610			
July	173,658	11,611	146,320			
August	163,184	10,768	141,174			
September	163,250	10,078	130,980			
October	166,850	9,958	139,531			
November	170,916	9,434	135,930			
December	175,418	9,530	133,548			
Total	1,991,238	132,765	1,655,434	331,130	17,055	254,208

Cooperative Refinery Association Rock Unit 3

Several properties in Rock field, Cowley County, Kans., were unitized in August 1955 for waterflooding. Figure 4 is a map of the unit showing production history of

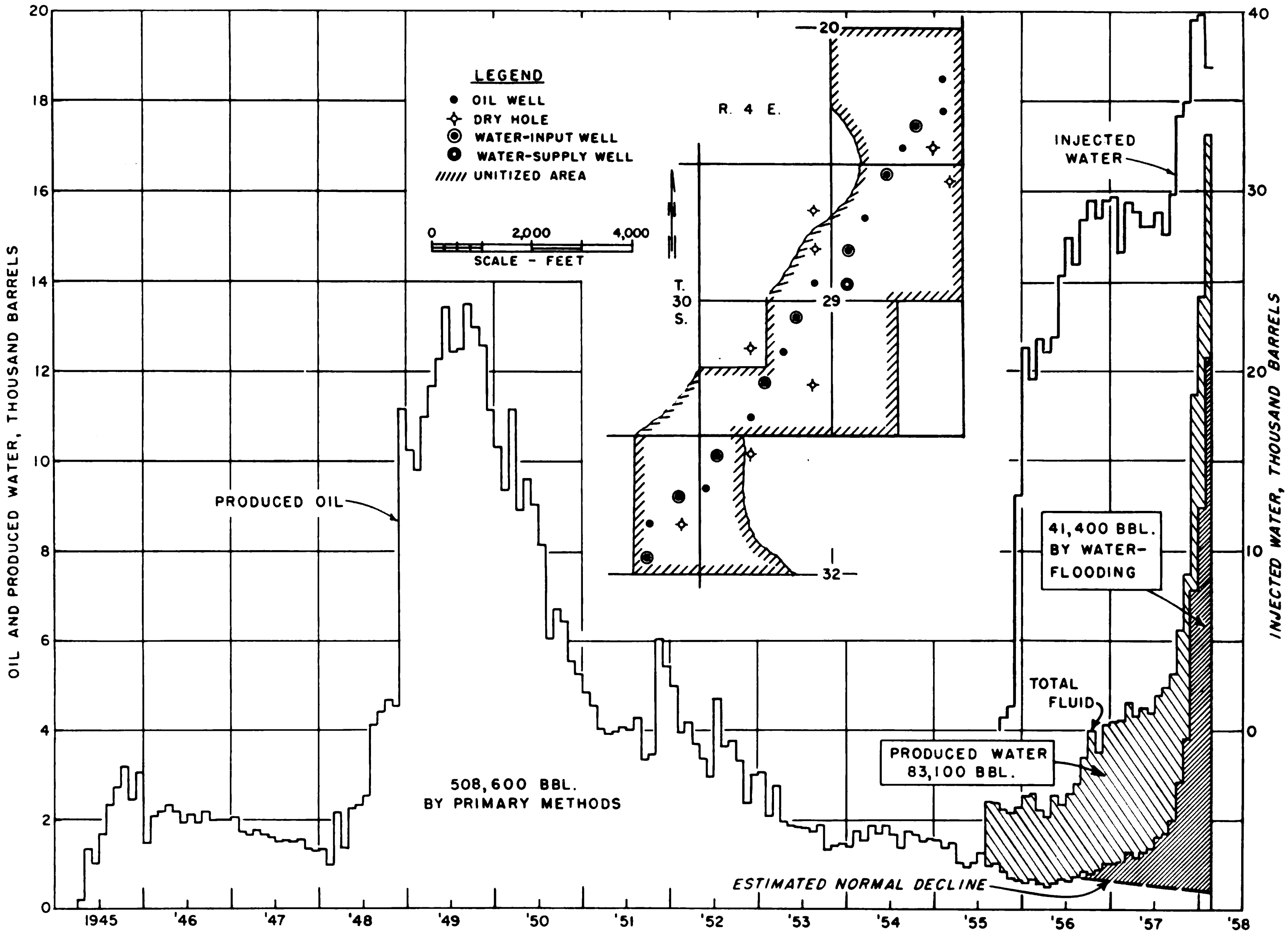

Figure 4. - Map and production history of Cooperative Refinery Association Rock Unit 3, Rock field, March 1, 1958.

the leases included in the project. In October 1955 the Cooperative Refinery Association began to inject water into the north input well in sec. 29, T. 30 S., R. 4 E., and by the end of 1955 the flood had been extended to include 8 input wells and 9 producing wells on 170 acres.

The formation flooded is the Bartlesville sand, which was deposited as a narrow bar approximately one-eighth mile wide extending about 2 miles in a northeast-southwest direction through the unitized properties in secs. 20, 29, 30, 31, and 32, T. 30 S., R. 4 E. The top of the sand ranges in depth from 2,786 feet at the north end of the stringer to 2,820 feet at the south end. The sand ranges in thickness from 9 to 26 feet and averages 18 feet. Analyses of cores taken on 2 wells in the NE1/4 sec. 31, before flooding, indicated that the formation in that area had the following average characteristics: Porosity, 21.2 percent; permeability to air, 46 millidarcys; oil saturation, 26 percent; and water saturation, 43 percent. Figure 5 is a graphic presentation of a core analysis. No core analyses from wells in the north part of the project were available.

Oil produced from the Bartlesville sand had an API gravity of 40.4° and a viscosity of 3.4 centipoises at 77° F. and 2.9 centipoises at 100° F.

History Before Flooding

The first wells on the property in sec. 20, T. 30 S., R. 4 E., were drilled in 1945. Development was slow; not until 1948 was the oil-productive area extended to the south by the drilling of five additional oil wells. After 1948 activity increased, and during the next few years nine oil wells were completed. Several dry holes defined the sand lens and indicated that the oil-productive area was approximately one location wide. Three of the wells in the south part of the property were hydraulically fractured in 1952 with favorable results. All wells were produced by primary methods until waterflooding was started in October 1955. Calculated on an estimated normal decline rate (fig. 4), approximately 500,000 barrels of oil would have been produced to March 1, 1958, by primary methods from the 17 wells on the 170 oil-productive acres in the property.

Method of Completing and Operating Wells

All the wells on the property were drilled to the top of the sand with rotary tools and then were completed with cable tools. The wells were shot with 2 to 2 1/2 quarts of solidified nitroglycerin per foot of effective sand, and 5 1/2-inch casing was set approximately 2 feet in the sand and then cemented with 60 sacks of cement. The cement plugs are drilled out and the wells are cleaned to bottom. The producing wells are equipped with 2-inch tubing, 5/8-inch rods, and insert pumps and are pumped by individual units powered by gas engines operating on propane.

Eight alternate oil wells along the axis of the sand stringer were converted to water-input wells by pulling the rods, pump, and tubing. A measuring line was run down the hole to determine the total depth of each well. Usually there had been very little fill-up, and the input wells were completed by installing meters and control valves. By March 1958 only 1 input and 1 oil well had required servicing.

Source and Treatment of Water

When the project was begun, produced brine from 2 wells in the SE1/4 sec. 20, T. 30 S., R. 4 E., was used for flooding. However, the supply of produced brine soon became inadequate, and a dry hole in the SE1/4SW1/4NE1/4 sec. 29, T. 30 S.,

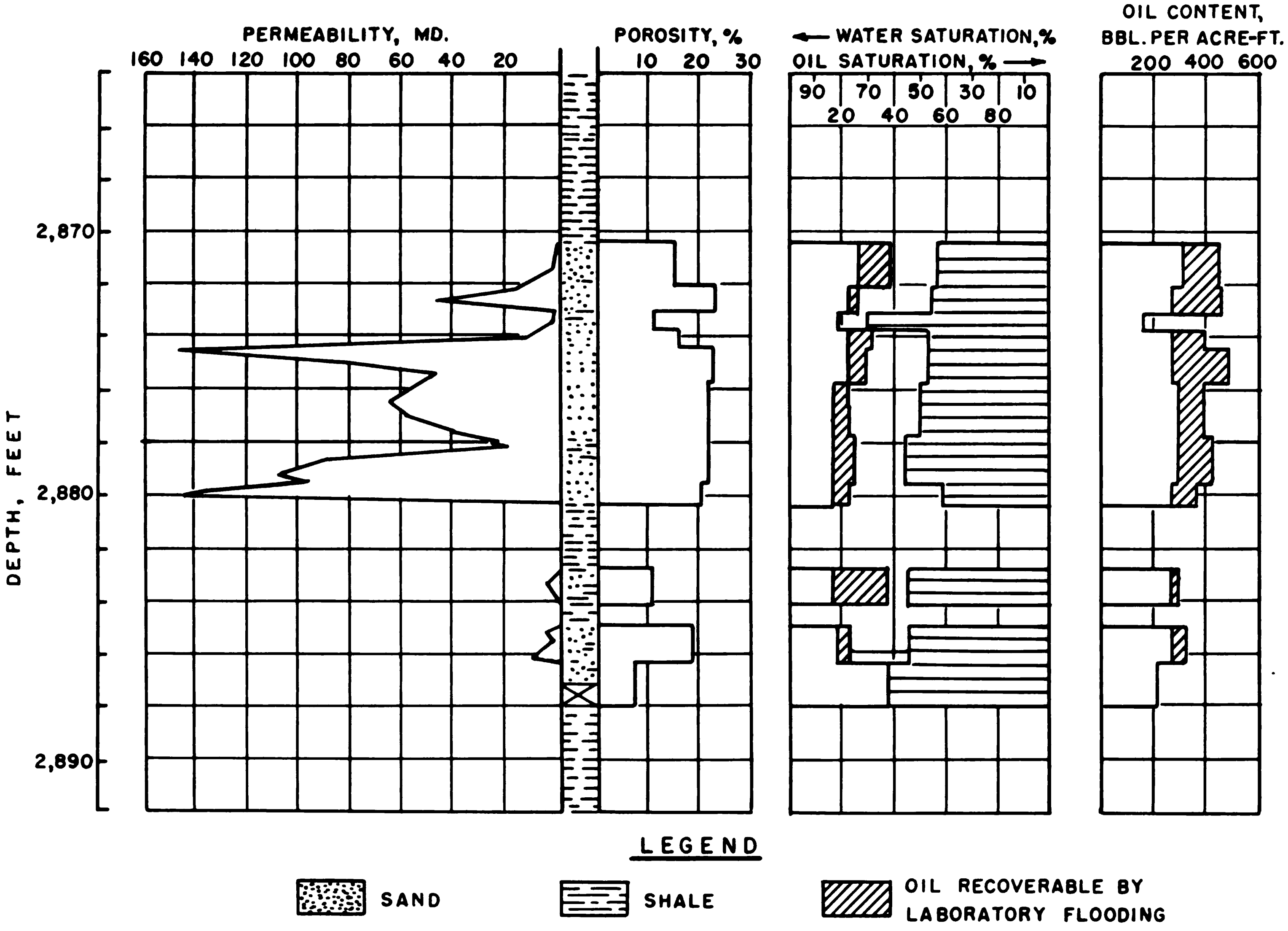

Figure 5. - Representative core analysis of Bartlesville sand, Cooperative Refinery Association Rock Unit 3, Rock field.

R. 4 E., was recompleted in the Stalnaker sandstone as a water-supply well. The well was washed down to 2,198 feet, where 7-inch casing was set and cemented with 600 sacks of cement. The casing was jet perforated in 4 zones at intervals of 1,911 to 1,990 feet. The well was then equipped with a common working barrel, 3-inch tubing, 7/8- and 1-inch tapered rods, and a heavy-duty pumping unit powered by a 55-hp. gas engine.

Before the pressure plant was completed in June 1957, water was pumped directly from the supply well into the distribution system without chemical treatment. Cement-lined 2- and 3-inch pipe is used in the water distribution system. More recently, brine from the supply well is pumped into a collecting tank, where it is mixed with water produced on the lease. The water in the 400-barrel collecting tank is treated daily with 1/2 gallon of a commercial wetting agent. The treated water flows through a filter into a 250-barrel clear-water storage tank. A 4- by 6-inch double-acting duplex pump takes water from the storage tank and forces it into the distribution system at a pressure of 200 p.s.i. The surface of the water in the collecting and storage tanks is covered by an oil seal to minimize the adsorption of oxygen from the air.

The filter is a permeable-plate type using a single grade of fine filter medium (0.6 to 0.8 mm. anthracite) supported on a layer of permeable aluminum-oxide plates. The filter is backwashed every other day into a tank, which also receives overflow water from the collecting and the clear-water tanks.

The collecting tank is connected directly to the clear-water tank and thus permits bypassing the filter during backwashing or when the input volume exceeds the capacity of the filter. The supply well is also connected by a bypass line leading directly into the distribution system.

The levels in the clear-water storage tank are controlled by a safety switch, which automatically shuts off the supply-well engine when the water level is 1 foot from the top of the tank and shuts off the injection pump when the water is 1 foot from the bottom of the tank.

The results of analyses of the Stalnaker water, produced water, and mixed water after treatment are shown in table 3. Some potential plugging material in the form of barium was found in each of the samples analyzed.

TABLE 3. - Mineral analyses of injection waters, Cooperative Refinery Association Rock Unit 3

Ions or radical	Supply-well water		Produced brine		Clear-well water	
	P.p.m.	Reacting values, percent (Palmer)	P.p.m.	Reacting values, percent (Palmer)	P.p.m.	Reacting values, percent (Palmer)
Calcium (Ca)	7,400	6.33	9,200	7.63	9,600	8.23
Magnesium (Mg)	2,800	3.95	2,550	3.48	2,830	4.00
Sodium (Na)	53,200	39.72	53,800	38.89	50,500	37.77
Bicarbonate (HCO_3)	73	.02	67	.02	85	.03
Carbonate (CO_3)	0	0	0	0	0	0
Sulfate (SO_4)	157	.06	0	0	116	.04
Chlorides (Cl)	103,200	49.92	106,700	49.98	103,000	49.93
Total solids	166,830	100.00	172,317	100.00	166,131	100.00
Hydrogen sulfide (H_2S)	None detected		None detected		None detected	
Barium (Ba)................	70 p.p.m.		6 p.p.m.		52 p.p.m.	
Specific gravity	1.113		1.116		1.117	

In August 1957 the wellhead pressure on 7 of the input wells began to decline, and by February 1958 most of the wells were taking about 10 barrels of water per foot of effective sand by vacuum. Wellhead pressures on the northeast input well, which adjoins the Rock Unit 2 flood, increased from 288 p.s.i. in October 1957 to 500 p.s.i. in November 1957. Since this pressure was higher than the rated pressure of the plant, the well was tied into the distribution system of the adjoining Rock Unit 2 flood.

Results of Flooding

The results of waterflooding operations are summarized in table 4. The first increases in rates of oil production attributable to waterflooding occurred in September 1956. During the 2 1/2 years the flood has been in operation, about 41,000 barrels of additional oil (fig. 4) has been recovered by injecting approximately 759,000 barrels of water. This is a cumulative water-injected to oil-produced ratio of 18 to 1 and a recovery of 244 barrels per acre from the 170 oil-productive acres in the flood.

TABLE 4. - Summary of operations, Cooperative Refinery Association Rock Unit 3, Rock field

Location - secs. 20, 29, 30, 31, and 32, T. 30 S., R. 4 E.
Sand flooded - Bartlesville
Depth to top of sand - 2,803 feet
Average sand thickness - 18 feet
Area flooded - 170 acres
Well pattern - alternate wells in a line

Type of water - brine
Type of system - closed
First injection - October 1955
First increase - September 1956
Status - active
Gravity of oil - 40.4° API
Viscosity of oil - 3.4 cp. at 77° F.
2.9 cp. at 100° F.

Data to March 1, 1958

	Barrels
Primary oil recovered (170 acres)	508,556
Primary oil recovered per acre (170 acres)	2,992
Oil recovered by waterflooding (170 acres)	41,420
Oil recovered per acre by waterflooding (170 acres)	244
Water injected	758,581
Water injected per acre (170 acres)	4,462
Water produced	83,090
Oil recovered (total)	549,976

Oil production, by years, barrels

1945	17,944	1950	96,767	1955	12,766
1946	24,265	1951	52,003	1956	8,411
1947	19,086	1952	43,969	1957	26,249
1948	41,874	1953	23,191	1958	1/21,173
1949	143,525	1954	19,655		

1/ 2 months' production.

TABLE 4. - Summary of operations, Cooperative Refinery Association Rock Unit 3, Rock field (Con.)

Summary of waterflood performance

Date	Acres flooded	Active input wells	Active oil wells	Oil recovery, bbl. per acre	Cumulative water-injected to oil-produced ratio
December 31, 1956	170	8	9	5	351
December 31, 1957	170	8	9	124	32
February 28, 1958	170	8	9	244	18

Monthly record of water injected and oil and water produced, barrels

	Water injected	Oil production			Water produced
		Total	Primary	Waterflood	
1955					
October	742	829	829		[2]4,196
November	1,440	681	681		1,439
December	13,116	663	663		1,593
Total	15,298	2,173	2,173		7,228
1956					
January	21,354	598	598		1,953
February	19,651	648	648		1,914
March	21,868	564	564		1,638
April	21,168	529	529		1,535
May	21,923	570	570		1,960
June	25,376	607	607		1,700
July	27,470	667	667		1,895
August	25,826	729	729		2.071
September	28,495	830	685	145	2,521
October	29,401	791	665	126	3,190
November	28,535	865	640	225	2,620
December	29,500	1,013	609	404	3,100
Total	300,567	8,411	7,511	900	26,097
1957					
January	29,684	1,011	605	406	3,163
February	26,612	1,029	585	444	3,148
March	29,362	1,201	565	636	3,430
April	28,786	1,178	545	633	3,120
May	28,065	1,295	530	765	3,210
June	28,076	1,354	512	842	3,040
July	28,835	1,627	496	1,131	3,155
August	28,051	1,668	480	1,188	3,234
September	29,826	2,016	468	1,548	3,204
October	34,321	2,868	450	2,418	3,403
November	35,020	3,851	437	3,414	3,641
December	39,612	7,151	424	6,727	4,310
Total	366,250	26,249	6,097	20,152	40,058
1958					
January	39,768	8,916	409	8,507	4,750
February	36,698	12,257	396	11,861	4,957
Total	76,466	21,173	805	20,368	9,707

[2] 3 months' production.

Anderson-Prichard Oil Corp. Deichman Project

The Anderson-Prichard Oil Corp. is testing the economic possibilities of waterflooding in the Deichman field, secs. 23 and 24, T. 31 S., R. 4 E., Cowley County, Kans. The project, covering 330 acres, is an experimental peripheral flood with an irregular pattern. A map and a graph of the production history of the leases in the project are shown in figure 6.

The formation flooded is the Bartlesville sand at an average depth of 2,875 feet. The oil-producing sand body is a small isolated lens, laminated with shale partings and averaging 30 feet in thickness. Sand fragments obtained during deepening and cleaning operations show that its characteristics are typical of other Bartlesville-sand lenses that produce oil in the county. Although no cores have been taken, most of the wells have been surveyed by radioactive logging methods to obtain most of the relative characteristics of the formation. A typical radioactivity log is shown in figure 7.

Oil produced from the formation had an API gravity of 41.3° and a viscosity of 3.4 centipoises at 77° F. and 2.9 centipoises at 100° F.

History Before Flooding

The discovery well in the Deichman field was drilled in December 1941 on the Deichman farm in sec. 24, T. 31 S., R. 4 E. Development of the field was slow, limited by a critical shortage of pipe and materials during the war years. Most of the primary drilling was completed by the end of 1949, when 25 oil-producing wells had been drilled. Three additional wells were completed, 1 in 1952 and 2 in 1953. Oil was produced by primary methods until waterflooding was begun in April 1957. The graph of the production history of the leases in the waterflooding project shows that in 1947 the annual rate of oil production from the 330 acres reached a peak of more than 150,000 barrels. Oil production declined rapidly to a minimum rate of 8,000 barrels per year in 1957, when 15 of the 28 wells were cleaned and converted to water-input wells for flooding.

Method of Completing and Operating Wells

Originally the wells were drilled with both cable and rotary tools; 5 1/2-inch casing was set and cemented near the top of the sand. However, a standard completion procedure had not been followed, and in some of the wells the sand body was not penetrated entirely, while in others the casing was set above the sand with the shale exposed.

At the beginning of the waterflood all of the wells were cleaned and, where necessary, the sand section was completely penetrated. In those wells in which the casing was cemented above the sand a 4 1/2-inch liner was run, cemented, and perforated opposite the sand section with 4 shots per foot.

Originally the wells were shot with 1 1/2 to 2 1/2 quarts of nitroglycerin per foot of sand. Records show that 1 well was shot with 325 quarts of nitroglycerin and that 1 of the wells completed in 1952 was fractured hydraulically.

Wells arranged in a peripheral[3] flooding pattern were selected as input wells, the rods and tubing were removed, and the input wells were connected to the water distribution system.

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[3] Staggered edge wells.

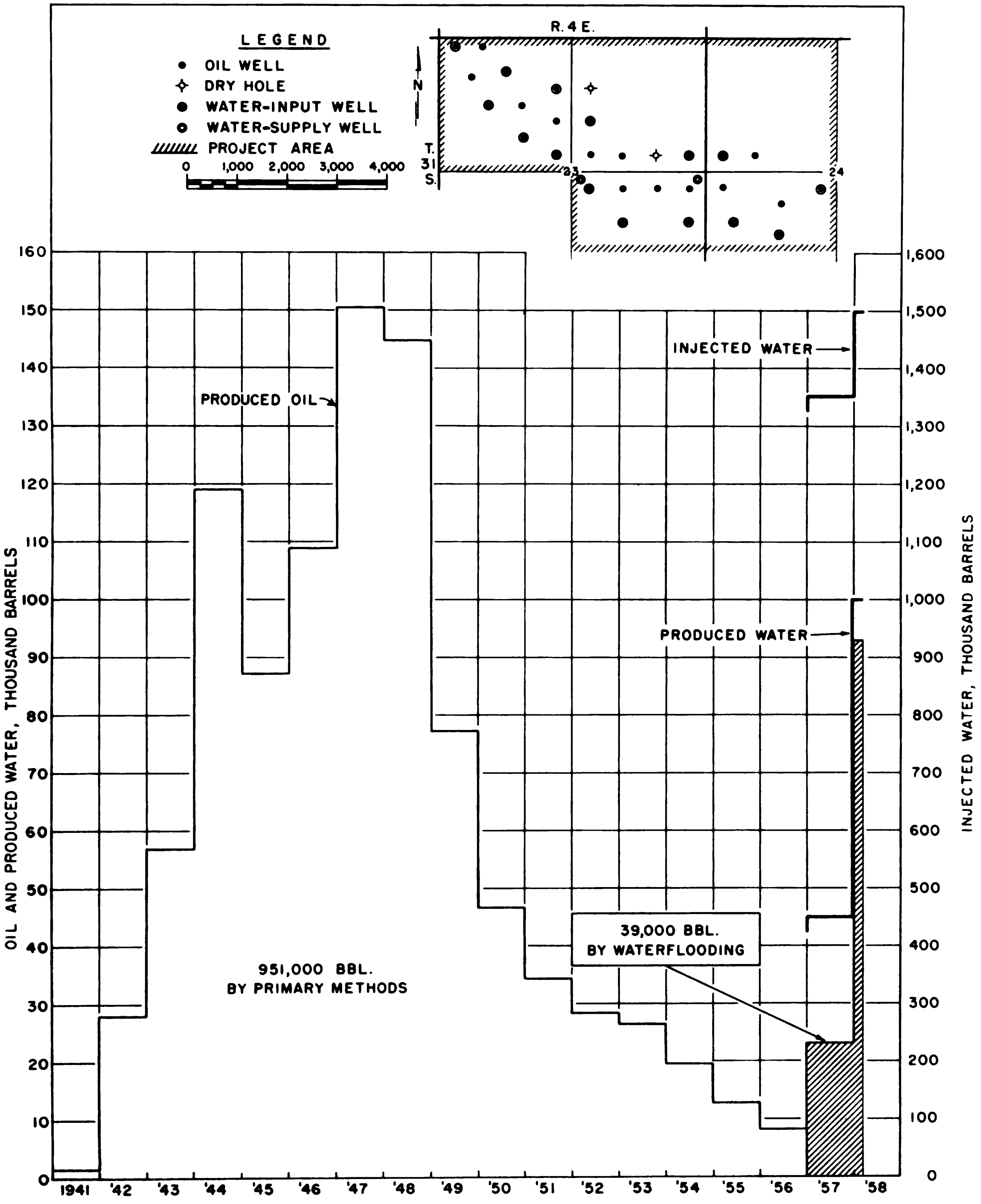

Figure 6. - Map and production history of Anderson-Prichard Oil Corp. Deichman project, Deichman field, March 1, 1958.

The producing wells were equipped for pumping with 2-inch upset tubing, rods, and working barrels. Two units are pumped with the original individual gas engines using butane gas. The other units are powered by 30-hp. electric motors.

Source and Treatment of Water

Brine for flooding is obtained from 2 supply wells completed at an average depth of 1,900 feet in the Stalnaker sand with 5 1/2-inch casing set and cemented through the water-bearing sand. The casing was perforated selectively (4 holes per foot) through 30 feet of sand. Each well has a measured capacity of 2,600 barrels of water per day and is pumped by a 40-hp. submersible electric pump on 3-inch steel tubing at a depth of 1,300 feet. The pumps deliver brine from the wells into three 300-barrel steel storage tanks at the water-pumping plant.

Produced brine from the tank batteries flows by gravity through 3- and 4-inch lines to the water-pumping plant. It is mixed with water from the supply wells by entering a 6-inch header connected to the base of each tank and through an individual spreader within each tank. An oil seal and natural gas piped from a nearby tank battery are maintained above the water surface in each tank to minimize the absorption of air into the water system. Injected water is neither treated nor filtered.

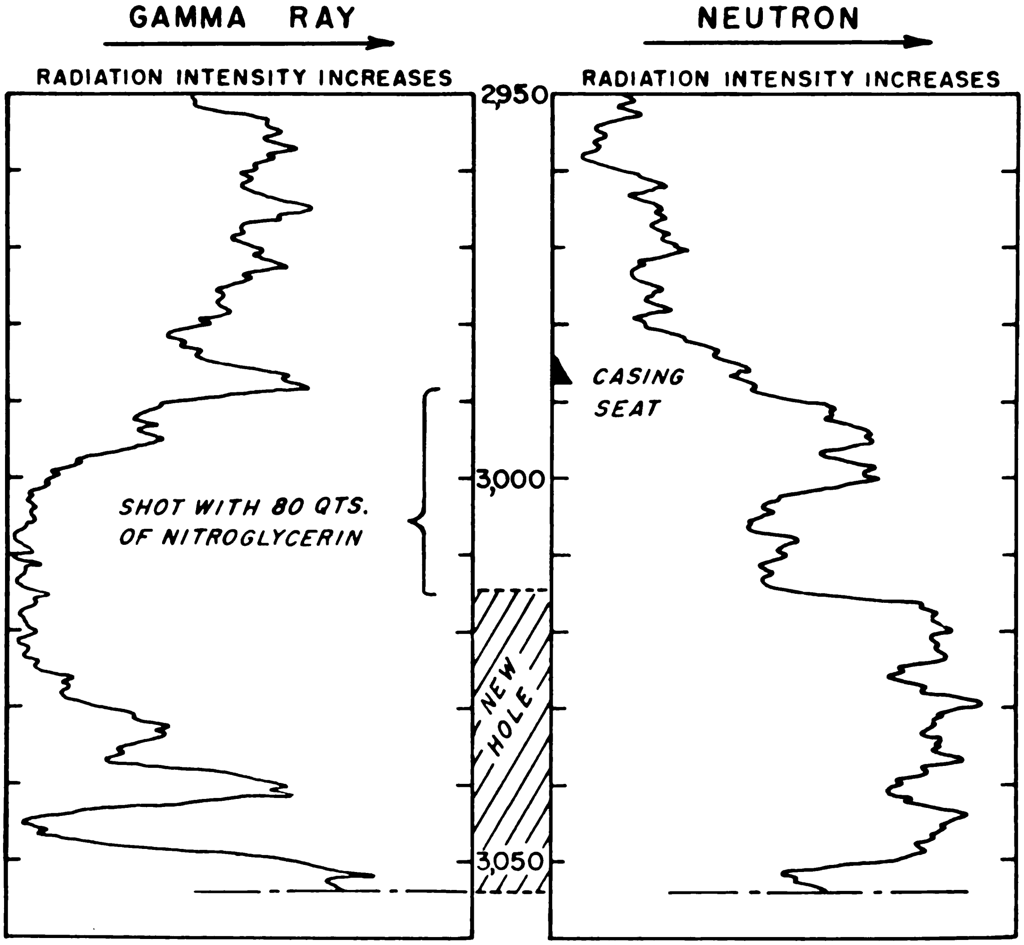

Figure 7. - Representative radioactivity log of Bartlesville sand, Anderson-Prichard Oil Corp. Deichman Project, Deichman field.

The results of analyses of the produced water, brine from the supply wells, and the mixed water are shown in table 5. It has not been necessary to backflow or clean any of the input wells since waterflood operations were begun.

TABLE 5. - Mineral analyses of injection waters, Anderson-Prichard Oil Corp. Deichman project

	Supply-well water		Produced brine		Clear-well water	
Ion or radical	P.p.m.	Reacting values, percent (Palmer)	P.p.m.	Reacting values, percent (Palmer)	P.p.m.	Reacting values, percent (Palmer)
Calcium (Ca)	6,700	6.31	11,300	9.50	7,300	6.74
Magnesium (Mg)	2,100	3.25	2,520	3.50	2,360	3.59
Sodium (Na)	49,300	40.44	50,400	37.00	49,300	39.67
Carbonate (CO_3)	0	0	0	0	0	0
Bicarbonate (HCO_3)	104	.03	12	0	116	.04
Sulfate (SO_4)	trace	0	48	.02	63	.02
Chlorides (Cl)	94,000	49.97	105,000	49.98	95,700	49.94
Total solids	152,204	100.00	169,280	100.00	154,776	100.00
Hydrogen sulfide (H_2S)	None		None		None	
Barium (Ba)	60 p.p.m.		21 p.p.m.		72 p.p.m.	
Specific gravity	1.103		1.120		1.106	

The mixed brine flows by gravity through an 8-inch line from the storage tanks to 2 horizontal triplex pumps. These pumps, powered by 100-hp. electric motors, are equipped with 3 1/4- by 6-inch ceramic plungers. A wall constructed of corrugated plastic separates the pumps from the motors and safeguards the motors and the control panel from possible leaks in the piping.

A meter house is an integral part of the main plant. The 2-inch lines serving 8 input wells are connected to a main waterline. Each well has a meter and control valves in the plant, where the individual well pressures can be read from a gage on the control panel. Connections at each well also enable the pressures to be read at the wellhead. A 4-inch water distribution line delivers brine to a second water-meter house, which serves 7 input wells. A system of automatic controls regulates the water level in the storage tanks, turning the submersible electric pumps on or off as needed. A set of maximum and minimum controls on the main waterline prevents excessive pressure or shuts down the pumps when a waterline breaks. Additional thermal- or pressure-type switches prevent overheating of the motors and regulate the oil levels in the pumps.

Results of Flooding

Good results have been achieved on this project during the short period of its operation. To March 1, 1958, more than 39,000 barrels of oil has been recovered by the injection of approximately 1.7 million barrels of water, resulting in a cumulative water-injected to oil-produced ratio of 51 to 1. This ratio is the result of the development of the project as a peripheral flood. A large volume of water was required to obtain reservoir fill-up over a larger area. To March 1, 1958, only a few of the oil-producing wells in the area had been affected. However, the results obtained from these wells have been gratifying and indicate excellent possibilities for the future recovery of additional oil.

TABLE 6. - Summary of operations, Anderson-Prichard Oil Corp. Deichman project, Deichman field

Location - secs. 23 and 24, T. 31 S., R. 4 E.
Sand flooded - Bartlesville
Depth to top of sand - 2,875 feet
Average sand thickness - 30 feet
Productive acres - 330 acres
Area flooded - 330 acres
Well pattern - peripheral

Type of water - brine
Type of system - closed
First water injection - April 1957
First oil increase - July 1957
Status - active
Gravity of oil - 41.3° API
Viscosity of oil - 3.4 cp. at 77° F.
2.9 cp. at 100° F.

Data to March 1, 1958

	Barrels
Primary oil recovered (330 acres)	951,298
Recovered per acre (330 acres)	2,883
Oil recovered by waterflooding (330 acres)	39,142
Oil recovered per acre by waterflooding (330 acres)	119
Water injected	1,682,220
Water injected per acre	5,097

Oil production, by years, barrels

1941	1,559	1947	150,700	1953	26,506
1942	28,137	1948	145,104	1954	19,926
1943	56,911	1949	77,007	1955	12,984
1944	119,123	1950	46,939	1956	8,235
1945	87,431	1951	32,466	1957	1/23,608
1946	109,852	1952	28,418	1958	2/15,534

Summary of waterflood performance

Date	Acres flooded	Active input wells	Active oil wells	Oil recovery, bbl. per acre	Cumulative water-injected to oil-produced ratio
December 31, 1957	330	15	12	72	57
February 28, 1958	330	15	12	119	51

Monthly record of water injected, water and oil produced, barrels

	1957			1958		
	Water injected	Oil produced	Water produced	Water injected	Oil produced	Water produced
January	-	-	-	169,458	7,457	16,471
February	-	-	-	156,944	8,077	17,820
March	-	-	-			
April	110,477	300	291			
May	158,870	539	406			
June	151,720	313	477			
July	146,641	1,608	2,545			
August	157,267	2,992	3,651			
September	149,427	3,546	3,814			
October	159,583	4,135	8,382			
November	151,983	4,359	10,515			
December	169,850	5,816	15,764			
Total	1,355,818	23,608	45,845	326,402	15,534	34,291

1/ Waterflooding begun.

2/ 2 months' figures.

Aladdin Petroleum Corp. Baird-Drennan Project

Waterflooding on the Aladdin Petroleum Corp. Baird-Drennan project in secs. 29 and 32, T. 34 S., R. 3 E., Gibson field, Cowley County, Kans. was begun in January 1955. Figure 8 is a map showing production history of the project.

Produced Bartlesville and Arbuckle brines are injected into the Bartlesville sand, which lies at a depth of 3,400 feet and averages 25 feet in thickness. In general, the maximum thickness of this sand is along the western edge of the two 160-acre leases included in the project. The sand was thin or absent in wells drilled on the adjoining properties to the east. Because of the irregularity of the sand, only 260 of the 320 acres was developed for primary production on 10-acre spacing. A representative electric log and core analysis are shown in figure 9. This core analysis indicates a relatively high porosity of about 25 percent through the main sand body at depths between 3,375 and 3,393 feet. The porosity of the upper part of the sand averages about 20 percent, whereas the porosity of the lower section averages about 15 percent. Permeability of the main portion of the sand body is fairly uniform at about 130 millidarcys with lower permeability above and below. Because these cores were cut while water-based mud was being circulated, it is assumed that the cores were flushed during the drilling. The resultant low oil saturation, ranging from 10 to 23 percent, is not representative of the uncontaminated sand. Likewise, the relatively high water saturation is assumed to contain some drilling fluid.

Analysis of a sample of oil from a representative well shows a gravity of 33.4° API and a viscosity of 11.5 centipoises at 77° F. and 8.7 centipoises at 100° F.

History Before Flooding

The first wells on the property were drilled in late 1951 and early 1952, but drilling was continued during the next several years, four wells being completed in 1955 soon after waterflooding was begun. Wells were drilled with rotary tools and cased with 5 1/2-inch casing set at the top of the sand and cemented with 150 sacks of cement. The bottom-hole pressure of the first wells completed in the Bartlesville sand was 1,764 p.s.i. Some of the wells were fractured by the original Hydrofrac process, but later wells were completed with sand-oil treatment, using larger volumes of oil and sand. Initial potentials ranged from 300 to 3,000 barrels of oil a day. On the south lease (the Baird-Drennan lease) six wells originally were completed in the Arbuckle limestone. Since the Arbuckle wells had large initial-production rates, they produced a disproportionately larger share of the lease production during the first few years. Because of the rapid decline in the rate of oil production and an increase in water production, in 1956 one of the original Arbuckle wells was plugged back to the Bartlesville sand and another to the Simpson formation.

Method of Completing and Operating Wells

The west input well on the north lease and the north input well on the south lease were converted from oil production to water injection in January 1955. Rods and tubing were pulled, and a swedged nipple was screwed in the top of the 2-inch casing collar. Later two other oil wells were converted to input wells.

The Bartlesville-sand wells are pumped by individual pumping units. Two of these units are powered by 15-hp. electric motors and the others by 10-hp. electric motors. Wells are pumped intermittently, their operating time depending upon the quantity of fluid produced.

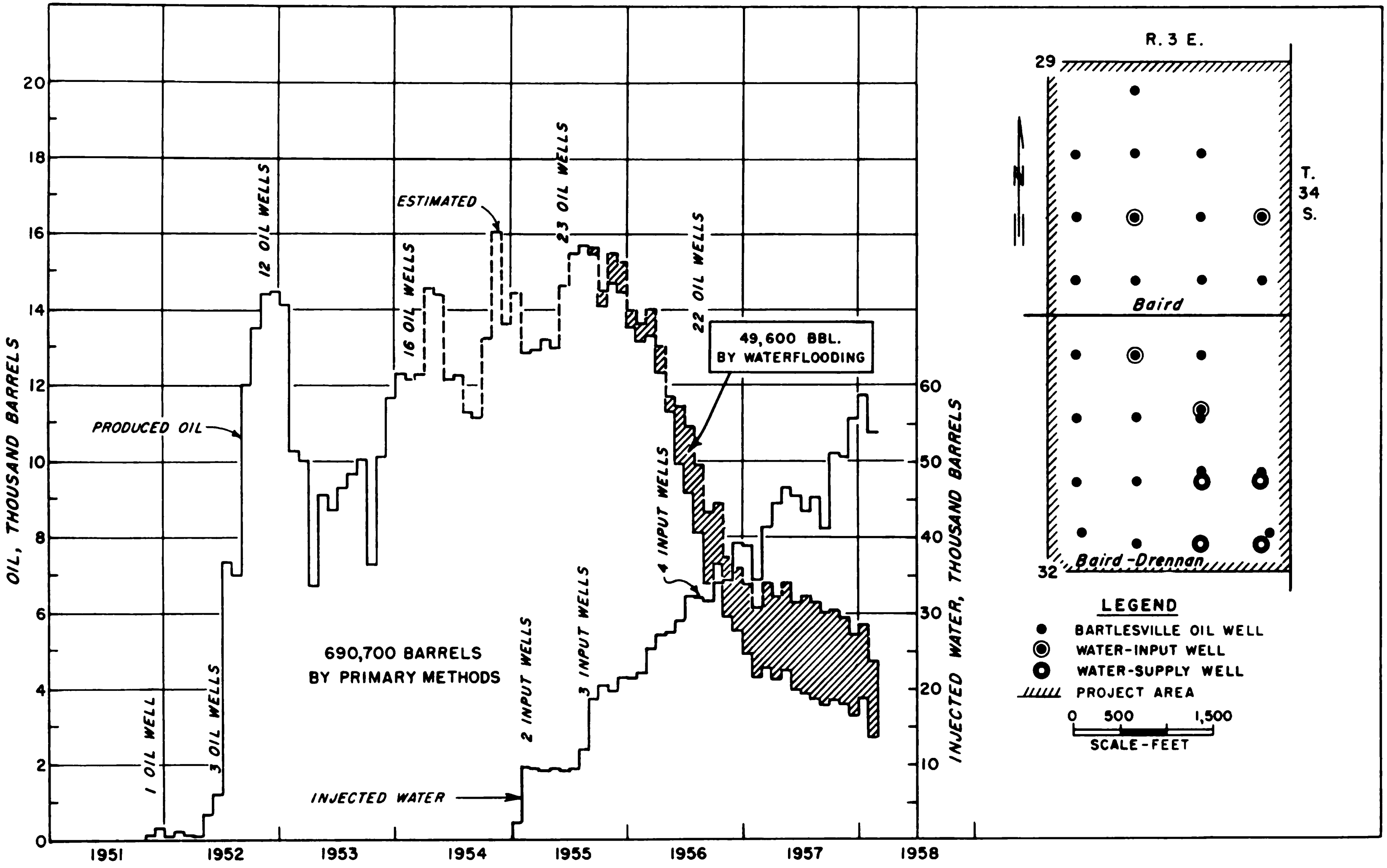

Figure 8. - Map and production history of Aladdin Petroleum Corp. Baird-Drennan project, Gibson field, March 1, 1958.

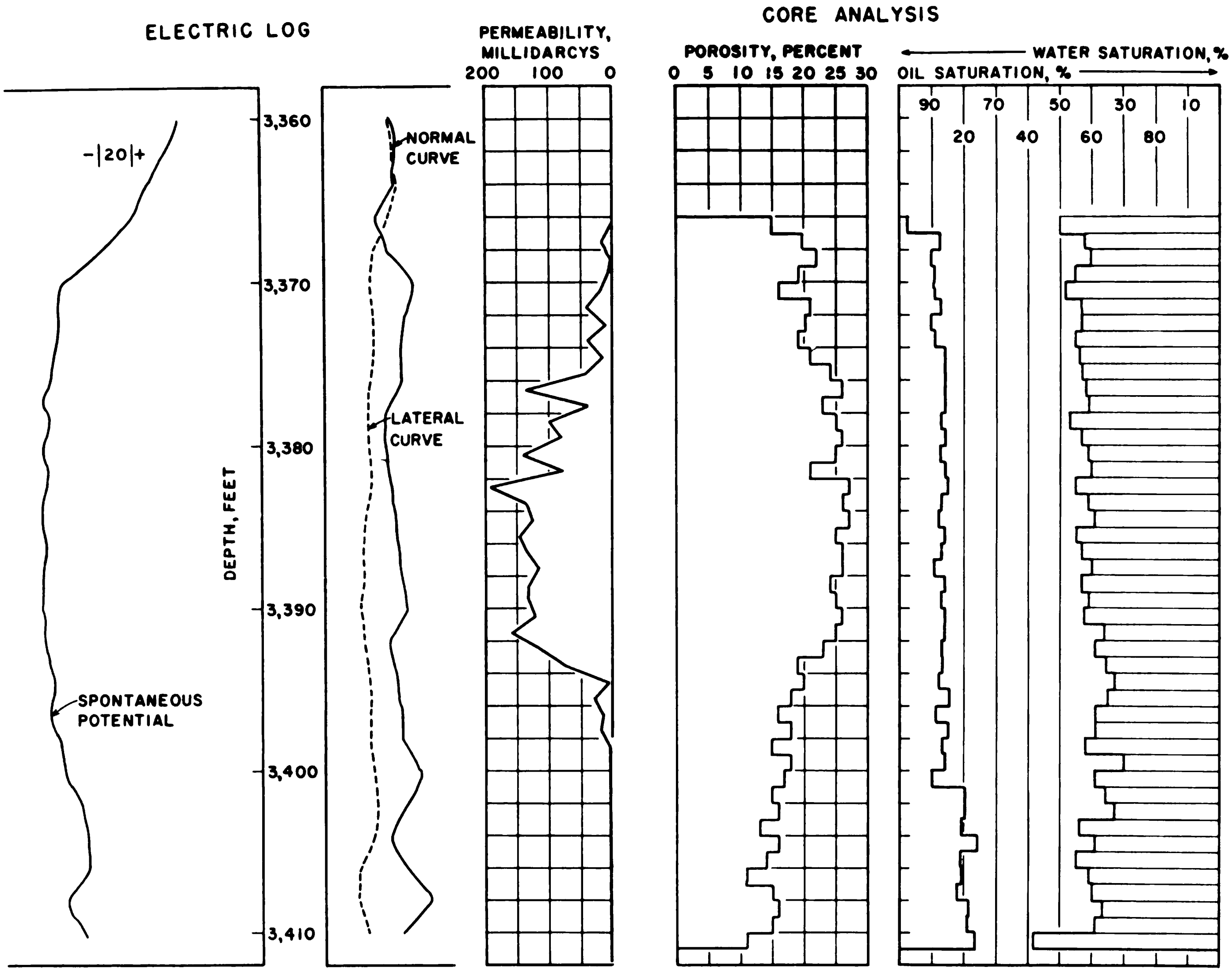

Figure 9. - Representative electric log and core analysis of Bartlesville sand, Aladdin Petroleum Corp. Baird-Drennan project, Gibson field.

Three electric-power units generate power for the entire operation, using natural gas from the lease to generate 3-phase, 440-volt current. A substantial saving has been effected by using these generators.

Since August 1955 the oil- and water-production rates of all wells on the property have been tested semiannually. From November 1951 until February 1954 oil production from the two leases came from the Bartlesville sand. However, after the completion of six Arbuckle wells on the Baird-Drennan lease in 1954, both Arbuckle-lime and Bartlesville-sand productions were recorded together. The oil-production curve shown in figure 9 represents an estimate of the Bartlesville-sand production based upon the percentage of Bartlesville oil produced during the periodic tests. Because the first complete test was made in August 1955, approximately 1 1/2 years after the first Arbuckle well was completed, little definite information is available regarding the volume of oil actually produced from the Bartlesville sand during that period. Tests in August 1955 showed that 59 percent of the oil production from the south Baird-Drennan lease came from the Bartlesville-sand wells. As the water injection became more effective and the rate of oil production from the Arbuckle wells continued to decline, the percentage of the total oil from the Bartlesville sand on that lease increased to 75 percent in August 1957. For this reason the oil-production curve shown in figure 9 is dotted for the period after February 1954.

Source and Treatment of Water

The west input well on the north Baird-Drennan property receives by gravity flow about 550 barrels a day of untreated and unfiltered brine produced from the 10 Bartlesville-sand wells on that lease. The other input well on the north lease and the 2 input wells on the south lease receive brine produced with the oil from the Baird-Drennan wells. About 70 percent of this water is from the 4 Arbuckle wells, shown as water-supply wells in figure 8. Water separated from the produced oil is collected in a 550-barrel covered wooden tank and pumped to a 25- by 50-foot aerating pit. A float control on the covered wooden tank actuates a valve and the switch of a pump, which forces water through spray nozzles in the aerating pit. Dry lime is added to the aerated water as it flows into a settling pit. During the summer months copper sulfate is added to control organic growths. As the water flows through the 50- by 100-foot settling pit, it is directed around and under 3 corrugated transite baffles to provide for additional settling time. Both aerating and settling pits are lined with an asphaltic-base paper to prevent leakage. Water from the settling pit flows to a sump in one corner of the pumphouse, where it is picked up by a centrifugal pump, powered by a 5-hp. motor, and forced through 2 sand-packed 500-gallon closed filters. A chemical-feeder pump injects daily about 1 quart of a corrosion inhibitor into the line ahead of the filter. Filtered water is collected in a 550-barrel clear-water tank. A float on this tank starts and stops the centrifugal pump, which forces water through the filter. The filters are backwashed once daily by a 4-inch centrifugal pump powered by a 7-hp. electric motor. Backwashed water is delivered to the settling pits. A horizontal triplex pump with 2 1/4-inch plungers, driven by a 10-hp. electric motor, delivers water through 3-inch main lines to the 3 water-input wells. A horizontal duplex 2- by 3 1/2- by 5-inch pump is maintained for standby service.

Table 7 shows the results of analyses of the water produced from the Arbuckle wells, mixed water from the aerating pit, and water prepared for injection after chemical treatment and filtering.

TABLE 7. - Mineral analyses of injection waters, Aladdin Petroleum Corp. Baird-Drennan project

	Arbuckle supply well		Mixed brines, untreated		Clear-well water	
Ion on radical	P.p.m.	Reacting values, percent (Palmer)	P.p.m.	Reacting values, percent (Palmer)	P.p.m.	Reacting values, percent (Palmer)
Calcium (Ca)	7,050	8.46	7,300	7.73	7,100	7.86
Magnesium (Mg)	1,530	3.02	1,660	2.90	1,600	2.92
Sodium (Na)	36,900	38.52	42,600	39.37	40,700	39.22
Carbonate (CO_3)	0	0	0	0	0	0
Bicarbonate (HCO_3)	109	.04	92	.03	37	.01
Sulfate (SO_4)	141	.07	205	.09	153	.07
Chlorides (Cl)	73,600	49.89	83,300	49.88	79,800	49.92
Total solids	119,330	100.00	135,157	100.00	129,390	100.00
Hydrogen sulfide (H_2S)	None		None		None	
Barium (Ba)	do.		do.		do.	
Specific gravity	1.086		1.091		1.088	

The volume of the injection water is metered at each input well. In March 1958 all wells were taking water under vacuum. Three of the input wells each were receiving daily about 500 barrels of water and the fourth well, about 250 barrels.

Results of Flooding

Water injection was started in January 1955, using a converted well on the north lease, and in February of the same year a well near the north edge of the south lease was converted for injection. New oil wells completed shortly thereafter masked any early gains from waterflooding. Three wells offsetting the input well on the north lease were completed after injection was started. Thus, all of their production may have been affected by water injection, although the specific quantity is not known. One of the Arbuckle wells on the south lease (Baird-Drennan) was completed in June 1955 after water was injected into the two wells mentioned above. In August 1955 tests were made to determine the daily oil and water production of all wells on the property. The volume of oil gained by waterflooding has been estimated from these and later periodic tests. At least 1 well showed an increase in the rate of oil production by August 1955, and by September of the same year 2 other wells were affected.

When the wells were tested again in March 1956, three Bartlesville-sand wells had shown increased oil production attributable to waterflooding. At that time no well in the area had shown an increase in the rate of water production. A third input well was added in September 1955 and, although it is only 50 feet north of an oil well, the oil well has not yet shown an increase in the rate of water production. Wells on the property were tested again in September 1956, at which time four wells had shown increases in daily water production, although total water production on the project had declined.

Estimated monthly oil production resulting from waterflooding is shown in table 8, Summary of operations, and by hatching in figure 8. By March 1, 1958, about 49,600 barrels of oil could be attributed to the injection of about 1,165,000 barrels of water for an oil-produced to water-injected ratio of 23 to 1.

Daily water production from the two leases had increased from 443 barrels in September 1956 to 652 barrels in March 1958.

TABLE 8. - Summary of operations, Aladdin Petroleum Corp., Baird-Drennan project, Gibson field

Location - secs. 29 and 32, T. 34 S., R. 3 E.
Sand flooded - Bartlesville
Depth to top of sand - 3,400 feet
Average sand thickness - 25 feet
Area flooded - 200 acres
Well pattern - alternate wells

Type of water - Arbuckle brine
Type of system - open
First injection - January 1955
First oil increase - March 1955
Status - active
Gravity of oil - 33.4° API
Viscosity - 11.5 cp. at 77° F.
8.7 cp. at 100° F.

Data to March 1, 1958

	Barrels
Primary oil recovered, estimated (260 acres)	690,697
Primary oil recovered per acre, estimated (260 acres)	2,656
Oil recovered by waterflooding (200 acres)	49,600
Oil recovered per acre by waterflooding (200 acres)	248
Water injected	1,165,437
Water injected per acre (200 acres)	5,827
Oil recovered (total)	740,297

Oil production, by years, barrels

Year	Total project	Bartlesville sand	Water-flood
1951[1]	560	560	0
1952	72,649	72,649	0
1953	119,798	119,798	0
1954	205,527	156,317	0
1955	267,874	172,857	2,197
1956	169,264	132,223	15,861
1957	90,041	75,583	27,650
1958[1]	11,958	10,329	3,914

Summary of waterflood performance

Date	Acres flooded	Active input wells	Active oil wells	Oil recovery, bbl. per acre	Cumulative water-injected to oil-produced ratio
December 31, 1955	160	3	23	14	69
December 31, 1956	200	4	22	90	28
December 31, 1957	200	4	22	229	23
March 1, 1958	200	4	22	248	23

[1] 2 months' production.

TABLE 8. - Summary of operations, Aladdin Petroleum Corp., Baird-Drennan project, Gibson field (Con.)

Monthly record of water injected, oil produced, and waterflood oil, barrels

	1955			1956		
	Water injected	Oil produced	Water-flood oil	Water injected	Oil produced	Water-flood oil
January	2,673	14,013		21,572	14,001	437
February	9,836	12,921		22,807	13,659	467
March	9,700	12,966		25,518	14,012	659
April	9,300	13,256		27,465	13,097	729
May	9,700	13,011		27,547	12,696	1,406
June	9,300	14,666		29,222	11,459	1,531
July	9,700	15,462		32,556	10,950	1,795
August	11,846	15,783	31	32,488	9,925	1,861
September	18,300	15,666	232	31,870	8,718	1,929
October	20,200	14,502	459	34,253	8,985	1,738
November	19,640	15,355	639	34,560	7,518	1,622
December	21,248	15,256	836	39,744	7,203	1,687
Total	151,443	172,857	2,197	359,602	132,223	15,861
	1957			1958		
January	39,368	6,805	1,919	59,192	5,766	2,021
February	34,872	6,188	1,894	53,663	4,573	1,893
March	41,862	6,845	2,265			
April	44,782	6,432	2,227			
May	46,793	6,826	2,390			
June	45,754	6,320	2,382			
July	43,378	6,437	2,573			
August	45,796	6,330	2,602			
September	41,227	6,024	2,445			
October	50,890	6,044	2,401			
November	50,800	5,901	2,349			
December	56,000	5,431	2,203			
Total	541,522	75,583	27,650	112,855	10,339	3,914

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